Chapter 6
Using Raster DTM for Dike Modelling

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Abstract

Digital Terrain Models are necessary for the simulation of flood events. Therefore they have to be available for creating flood risk maps. River embankments for flood protection have been in use for centuries. Although they are artificial structures that actually do not belong to the natural elements of the land surface they are usually implicitly embedded in digital terrain data. Being elongated and elevated objects, they appear – depending on the used colour ramp for visualisation – as bright stripes on the surrounding background.

For purposes of flood protection it might be useful to gain data about crest levels, especially if these information are not available from other sources. High resolution Digital Terrain Models (DTM) can be used as highly reliable sources for deriving dike heights. Using laser scanner technique a general height accuracy of about 10–15 cm can be achieved for elevation models. Thus, by analysing DTM data relevant geometrical information on dikes can be directly derived.

6.1 Introduction

The last decades have shown a high frequency in the appearance of severe flood events in Central Europe. This tendency is continuing after the turn of the millennium, and the problem will probably become more serious in the future due to global warming.

Flood protection has therefore seen a change of paradigm within in the recent years and decades. In former times it was common to count only on technical protection strategies as building dikes, reservoirs, or flood polders.

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Recent flood events have shown the limited capacity of these measures. Today a more integrative view of flood protection is being adopted. The strategic focus here, which is of vital importance, lies on risk assessment and risk management. The current state of treating flood risks is given in [11].

Table 6.1 Selected European flood events since 1978. Source: [11]

Time	Event description
1978	Flood event in Switzerland changes Swiss flood protection strategies towards integrated approaches
1993, December	Rhine flood event, later declared as "Hundred Year Flood"
1995, January	Rhine flood event, overtopping the December event of 1993, overall damage 1993/95: > 5.5 billion EUR
1997, Summer	Oder Basin flood in Germany, Poland, Bohemia, more than 100 casualties, damage about 5.5 million EUR
1999	"Whitsun Flood" in Southern Germany, five casualties, damage 335 million EUR
2002, August	"Hundred Year Flood" in Central Europe, esp. in the Elbe and Danube basins, in Germany 21 casualties, overall damage of about 11.8 billion EUR
2003	Winter flood on the Elbe River
2005, August	Flood in Switzerland, the most expensive damage event of the last hundred years, overall damage about 2.6 billion CHF [16]
2006, March/April	Springtime flood along the Elbe River, partly with higher gauges compared to 2002 (esp. in the lower Elbe due to less dike breaches in the middle river stretch); Danube flood in Romania
2007, August	Flood event caused by heavy rain in Germany (Rhine), Switzerland, Austria

The list of recent flood events shown in Table 6.1 demonstrates the necessity to deal with flood risk management, especially in densly settled areas like Central Europe. Flood risk management can be seen as the effort to optimise the relation of hazard reduction – as erecting protection buildings – and vulnerability mitigation.[1] The latter can be achieved by the interaction of several components, e. g. to adopt resistant and resilient building structures. It is also of high importance to establish an efficient disaster management system which provides communication tools capable of working under hard pressure.

Another way of reducing vulnerability is to withdraw from natural floodplain areas. This improves the ecological capability and complies the natural conditions of a seasonally flooded river regime (see [4]). In [3] it is claimed to provide rivers with retention areas which have been successively reduced

[1] For detailed information on flood protection terms see [9].

to a fraction of their original sizes. The Elbe River has preserved much of its natural conditions and shows a relatively high ecological potential compared to other Central European riparian landscapes. Nevertheless, more than 80 % of the Elbe floodplains have been cut from the river during the last centuries (see [5]). A coarse map showing the differences between the former flooding area and the recent floodplain is shown in [15].

The research project VERIS-Elbe

The research project VERIS-Elbe [8] examines the changing flood risk along the German Elbe River due to land use change, climate change, and other factors using the scenario technique prospecting into the next one hundred years.

The potential flood area of the Elbe River in Germany covers about 5 000 square kilometres. Within the project it is intended to determine flood risks under varying conditions, which includes to remove dikes and rebuild them on other places.

6.2 Digital elevation data

6.2.1 Dikes as terrain model objects

Depending on the objective of the model one speaks of Digital Terrain Models or Digital Surface Models. The latter depict the surface including elevated objects while the former contain information only on the very earth's surface. Therefore it is useful and necessary not only to talk about Digital Elevation Models but exactly to determine what kind of elevation is meant.

The fertile floodplain soils are favourable for agrarian use and require protection. Therefore the beginning of dike formation dates back for centuries. Whereas flood dams were already erected by Roman soldiers the planned installation of dikes in Central Europe began in the early Middle Ages (see [14]).

The derivation of Digital Terrain Models includes the clearing up raw the data from elevated items like buildings, bridges, or trees. Contrary to this, dikes usually remain as land surface elements in the terrain model datasets. Depending on the visualisation colour scheme they appear as bright bands. Dikes therefore turn out to be a kind of hybrid objects which are man-made on the one hand, but on the other hand are considered as belonging to the earth's surface.

If one needs information about geometrical properties of dikes such as length, width, and height it is necessary to collect external data. Length and width can quite easily be obtained by using measurement tools as provided by standard GIS[2] software. Height information must be provided by terrestrial survey data or can be extracted directly from the DTM.

6.2.2 Available Digital Terrain Models

The research project VERIS-Elbe examines the flood risk on nearly the full length of the German Elbe River. The investigation area ranges from the German-Czech border to the gauging station Neu Darchau which is situated in Lower Saxony and is to be considered as the last gauge not influenced by the tides (see [1, p. 55]).

6.2.2.1 High resolution DTM

One of the project partners is the German *Bundesanstalt für Gewässerkunde*[3] *(BfG)* which is providing a high resolution Digital Terrain Model for the Elbe including the hydrologically relevant earth's surface along the river channel. That means that all flood protection dikes are included in the model. The model's acronym is DGM-W[4] and it is divided into three sections called South, Middle, and North. The spatial resolution is 2 m in section South – covering the Saxon part of the Elbe River – and 2 m in section Middle – covering the Elbe in Saxony-Anhalt as well as the area of the Havel River. Section North data have not been processed so far but will be at 2 m resolution as well once available. All these datasets were derived from laser scanner data. The river bed information origins from sonar measurements. The height accuracy is indicated as 0.15 m.

Another high resolution DTM is available for the Saxon Elbe section. It has been provided by the Saxon *Landestalsperrenverwaltung*[5] *(LTV)* and has a resolution of 2 m. It also covers the immediate neighbourhood of the river and has a height accuracy better than 0.10 m. This model has no specific acronym, but it is referred to as *HWSK data*[6] by the LTV.

The *Landesbetrieb für Hochwasserschutz und Wasserwirtschaft Sachsen-Anhalt*[7] *(LHW)* has provided a high resolution DTM for a projected flood polder site near Lutherstadt Wittenberg. It has a spatial resolution of 1.0 m and a height accuracy of 0.15 m.

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[2] Geographic information system

[3] Federal Institut of Hydrology, Koblenz, `http://www.bafg.de/`

[4] Digitales Geländemodell – Wasserlauf, engl.: DTM Watercourse

[5] State reservoir authority, Pirna, `http://www.talsperren-sachsen.de/`

[6] HWSK: Hochwasserschutzkonzeption, engl.: Flood protection conception

[7] State Agency for Flood Protection and Water Management Saxony-Anhalt, Magdeburg

Table 6.2 Available high resolution DTM datasets

DTM dataset	Spatial resolution [m]	Height accuracy [m]
HWSK data	2	0.10
DGM-W Middle	2	0.15
DGM-W South	2.5	0.15
Polder DTM	1	0.15

6.2.2.2 Medium resolution DTM

Unfortunately, the whole inundation area of the Elbe River cannot be covered with a high resolution DTM. Thus for the remaining regions a DTM provided by the German *Bundesamt für Kartographie und Geodäsie*[8] is being used. The DGM-D[9] is part of the ATKIS[10] dataset and has a spatial resolution of 25 m. The height accuracy varies within a quite large range. As stated in the dataset's manual [2] the accuracy is determined as ranging from 1 m to 8 m – depending on the quality of the underlying data. This quite high inexactness of the data is caused by the very different sources which have been used to compile the DTM that serves the whole country. In Germany the survey authorities are under the responsibility of the Federal States. The federal survey agencies are supplying data which is used by the BKG to compile datasets covering Germany as a whole. The data originate from very diverse sources and show different spatial resolution and accuracy. Some parts of the data are collected by laser scanning, stereographic interpretation of aerial imagery, or even might originate from digitising contour lines from large-scale topographic maps.

6.3 Dike extraction

6.3.1 Object recognition

Because dikes can be perceived as elevated objects, dike extraction leads to object recognition methods which are common in raster image processing.

Identification of dikes can generally be done by two different approaches. The first possibility uses pure image processing. These methods base on the analysis of elevation differences in the model. Fulfilling certain criteria causes the identification of pixels as belonging to an elevated object or not. The

[8] Federal Agency for Cartography and Geodesy, Frankfurt/M. and Leipzig, `http://www.bkg.bund.de/`

[9] DGM Deutschland, engl: DTM Germany

[10] Amtliches Topographisch-Kartographisches Informationssystem, engl.: Authoritative topographic cartographic Information system

second method uses pre-information. If vectors depicting the lineage of dikes are available the raster model can selectively be investigated. Using vector information it is no longer necessary to examine the whole terrain model for identifying dikes. In this paper only the first approach mentioned is discussed. In all cases an interpolation of the base heights of the detected dike bodies has to follow. The final step to establish the *Digital Dike Model (DDM)* is to calculate the actual crest levels. This leads to a raster based model which can be used as the basis for ongoing analysis.

Object recognition in DTM are based on the finding of sudden level leaps. If a given difference threshold Θ is exceeded the pixel is considered as an elevated object (see [10]). The further editing will appear as follows: The elevated flagged pixels are being erased from the terrain model and form a mask of non-ground points *(Non-Ground Model)*. Afterwards the remaining holes in the Digital Terrain Model must be filled with approximated ground height values, which have to be interpolated from the surrounding edge pixels. The actual crest level values can be obtained by subtracting the interpolated surface from the original elevation data.

6.3.2 Adapted Filter method

The principle of detecting elevated objects is to examine the surface level differences within a certain neighbourhood. If the difference between a pixel and its neighbouring minimum exceeds a defined threshold it is being marked as belonging to an elevated object.

It is useful to apply combinations of several filter sizes and threshold settings. The result of the filtering is being cleaned and will be used for building objects which are classified by shape parameters. As a result the actual crest level can be directly derived.

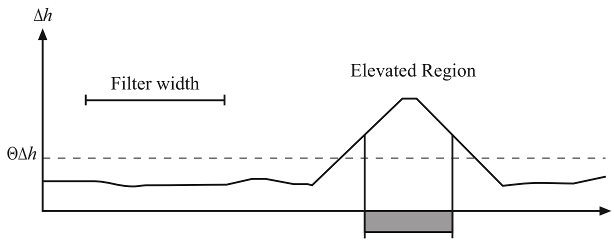


Fig. 6.1 Detection of elevated objects in DTM (inspired by [10]).

The principle of the filter method is illustrated in Fig. 6.1. Each pixel in the given DTM scene will be compared to its neighbourhood minimum whose extent is indicated by *filter width*. If the difference exceeds the threshold $\Theta_{\Delta h}$ the pixel will be flagged as elevated.

The filter method described in [10] was already applied by the author [7]. For the use with one of the above-mentioned high resolution DTM it had to be adapted and realised in a programming language available at the IOER[11]. The programme allows the user to adjust any options concerning the appliance of the filter to adequately fit the current conditions of the investigated DTM scene.

To detect elevated objects of different dimensions it is useful to combine the use of several filter sizes in combination with different threshold values. It can easily be seen that bigger filter widths combined with higher Θ-values will detect large elevated objects that have a relatively wide extent while a small filter size with lower thresholds would yield smaller objects of little height. In order to detect most of the elevated objects a combination of two option settings should be applied.

Height thresholds and filter sizes

The following facts have been used to preset the thresholds for discriminating elevated from non-elevated pixels:

Table 6.3 Flood alert levels in relation to dike height. Source: [13]

Alarm level	Event/characteristics for declaring
1	Bankfull riverbed, little overflowings occurring here and there.
2	Beginning overflow, water level reaches dike base.
3	Water level reaches half crest level, beginning dike defence measures if necessary.
4	Dike-overtopping threat, endangered dike stability.

Considering the parameters in Table 6.3 the dike's crest levels can be estimated as the difference of the water levels that belong to Alarm levels 4 and 1. Table 6.4 indicates the Alarm levels of selected water level gauging station along the Elbe River.

The differences between the values of alarm levels 4 and 1 in Table 6.4 suggest that dikes rise at least 2 m above the surrounding surface. Therefore the threshold $\Theta_{\Delta h}$ should not be bigger than 2 m.

In [7] dike width values were detected ranging from 12 m to 25 m that can be considered as indicatory values. The filter has to ensure that at least one ground point is inside the search window while passing over the DTM raster. Assuming a maximum dike width of 25 m the filter size then has to be 13 m.

[11] Leibniz Institute of Ecological and Regional Development, Dresden

Table 6.4 Flood alarm levels of selected Elbe gauges. Source: [12] and [6]

Gauging station (River km from Czech border)	Alarm level [cm] 1	2	3	4
Schöna (2)	400	500	600	750
Dresden (55.6)	350	500	600	700
Torgau (154.1)	580	660	720	800
Wittenberge (453.9)	450	550	630	670

For dikes do not elevate abruptly out of the surface, a smaller filter size with smaller threshold is to be applied in order to detect the lower parts of the dike slope. The application of the second filter can be reduced to the regions neighbouring to the pixels that have been detected by the larger filter window. Therefore these regions will be buffered and used as mask for the second filtering.

Object Selection

Some regions in the DTM might be detected which are not dikes or embankments. These include single pixels or small pixel groups which do not belong to any dike body. Therefore the Non-Ground Model have to be classificated if its objects can be dikes or not. That's why the recognised objects are described by form parameters:

Direct Parameters

are basic geometrical attributes which are calculated directly from the raster data:

- *Area*: The Area A is calculated by cumulating the count of pixels that form one object. This number is depending on the spatial resolution of the Digital Terrain Model used for dike detection.
- *Perimeter*: The perimeter P is formed by the outline of the surrounding pixels of one object and is therefore a multiple of the pixel width.

Indirect Form Parameters

are calculated from Area and Perimeter and describe the object shape independent from the actual object size:

- *Form Factor*: The Form Factor F is defined by the ratio of the squared Perimeter P and Area A: $F = P^2/A \geq 4\pi$. It describes the figure's deviation from the circle of which the Form Factor is $F_0 = (2\pi r)^2/2\pi r^2 = 4\pi$.

- *Contour Index*: The Contour Index C is given by the ratio $C = P/P_C \geq 1$, where P is the object perimeter and P_C is the circumference of an equal-area circle. For circular objects the Contour Index $C_0 = (2\pi r)/(2\pi r) = 1$.

The parameters F and C are related and can be converted by $F = 4\pi C^2$. Hence it is possible to describe the found objects by just one of the indirect parameters.

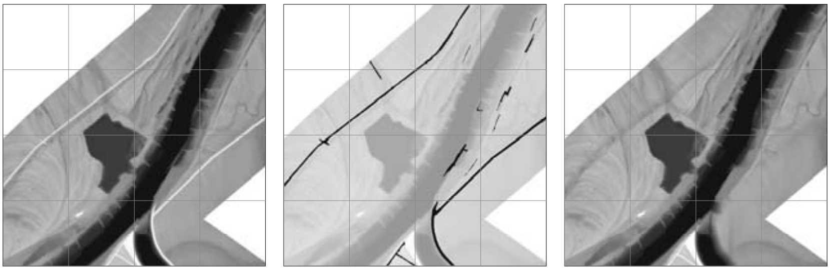
Once the objects have been build and their form parameters have been calculated they are classified as possible dikes or non-dikes by thresholding the two parameters Area and Form Factor.

1. One object must consist of a minimum number of pixels, that it has to cover a minimum area to be considered as possible dikes.
2. The Form Factor has to be greater than a certain threshold value which is typical for elongated features like dikes.

6.3.3 Filter appliance

The application of the two filters will lead to two *Non Ground Models* NGM_1 and NGM_2. Afterwards both models can be merged to produce the *Combined Non-Ground Model* NGM_{comb}.

Fig. 6.2 shows the consecution of the filtering. The analysed scene has dimensions of 2 000 m on both axes.



(a) DTM (b) NGM_{comb} (c) cDTM

Fig. 6.2 Demonstration of DTM filtering

The different stages of filtering are shown in the sub-pictures (a) to (c) of Figure 6.2:

(a) Original DTM. Dikes on both sides of the river are well exposed.
(b) Detected object areas for ground point interpolation after cleaning filter result.
(c) DTM after removing dikes (cDTM).

6.3.4 Ground level interpolation

Removing the detected objects includes the calculation of the underlying base heights in order to fill the masked pixels in the DTM. This can be accomplished quite easily by using the triangulation technique. The pixels bordering the masked areas function as mass points for the triangulation. The masked areas are of longish shape. So the distance which has to be filled by interpolation is not too far and the result of the triangulation can be considered as reliable. Figure 6.3 shows the principle of triangulating.

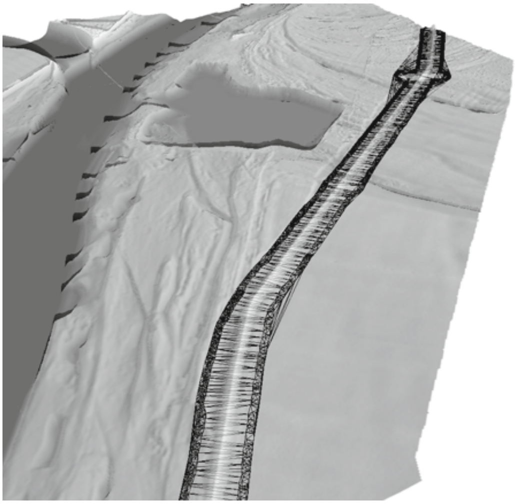


Fig. 6.3 TIN creation for base height interpolation

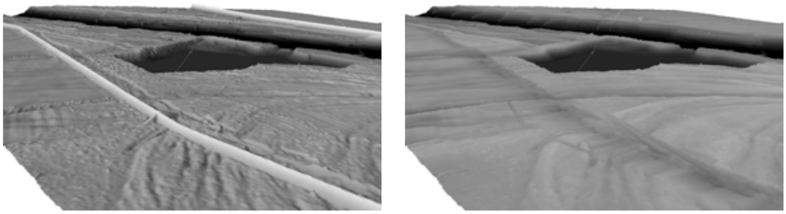
The resulting model is a Digital Terrain Model cleaned from dikes. For differentiation from the original version it should be abbreviated with cDTM (see Fig. 6.4).

Once all objects (dikes) have been erased and replaced by their ground heights the final *Above Ground Model* (AGM) can be calculated by subtracting cDTM from DTM: $AGM = DTM - cDTM$.

This model can be considered as the desired DDM (see 6.3.1). At this state it forms a raster where each pixel value represents the above ground level. To make clear it is of raster format the abbreviation should be extended to *DDM-R*. The single dikes are surrounded by no-data regions[12].

The focal maxima within the distinct objects give information on the real object height. Dike lineage can be derived by thinning and vectorising the data. The stored features of the polylines will hold attributes which indicate

[12] Depending on the further analysis it might be useful to use zero values to fill non-elevated areas instead of no-data.



(a) Original DTM (b) Cleaned cDTM

Fig. 6.4 DTM scene before and after detecting and removing dikes

important geometrical information as object heights and widths. This dataset is referred to as *DDM-V*. Because it consists of vector data it can easily be edited and manipulated with common GIS methods. Changes can be re-converted into raster format for further use in flood simulations.

6.4 Outlook

The technology described in this paper offers a quite effective method to extract dikes from high resolution DTM data. This is useful especially if no geometrical data concerning the dikes is available. Another aspect is to verify given information on crest levels, e. g. on medium and large scale[13] topographic maps. The procedures have been programmed in *Arc Macro Language (AML)* scripts. A user friendly version for ArcGIS is intended which includes dike detection and dike removal as well as the establishment of new dikes. Therefore the user will have to digitise the new dike lineage in vector format. The vectors' attributs include information on crest levels and dike widths and/or slope ratios from which a new dike can be modelled and merged with the underlying DTM.

This will provide a useful toolbox to estimate the effect of dike building measures or dike breaches on the flood risk of a certain area. The main problem will remain the limited availability of high resolution DTM which is the most important pre-condition of object recognition.

[13] Medium scale: ≥1:10 000–>1:100 000, large scale: >1:10 000

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